A New Superframe Scheme to Reduce Delay in IEEE 802.15.4

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Abstract: - The key features of low-rate wireless personal area networks (LR-WPAN) are the low data rate, low cost, and low power consumption. LR-WPAN is very useful in many applications such as detection, remote control, tracking, and monitoring. In particular, the data delay is very important in detection and remote control in WPAN. In this paper, we propose a superframe structure for LR-WPAN to reduce the delay to transfer data from the source to the destination. Our scheme can reduce overall mean data delay of between any pair of devices by reducing waiting time of data generated during inactive period.

Keywords: low-rate wireless personal area networks (LR-WPAN), superframe structure, wireless sensor networks, ZigBee.

1 Introduction

Recently, WPAN is one of most essential technologies for implementing ubiquitous computing. Wireless personal area networks (WPANs) are used to convey information over relatively short distances. Unlike wireless local area networks (WLANs), connections effected via WPANs involve little or no infrastructure. This feature allows small, power-efficient, inexpensive solutions to be implemented for a wide range of devices.

IEEE 802.15.4 would be widely adopted for various applications such as detection, remote control, tracking, and monitoring [1][2]. The scope of IEEE 802.15.4 [3][4] is to define the physical layer (PHY) and medium access control (MAC) sublayer specifications for low data rate wireless connectivity with fixed, portable, and moving devices with no battery or very limited battery consumption requirements typically operating in the personal operating space (POS) of 10 m. It is foreseen that, depending on the application, a longer range at a lower data rate may be an acceptable trade-off. The purpose of IEEE 802.15.4 is to provide a standard for ultra-low complexity, ultra-low cost, ultra-low power consumption, and low data rate wireless connectivity among inexpensive devices. The row data rate will be high enough (maximum of 250 kb/s) to satisfy a set of simple needs such as interactive toys, but scalable down to the needs of sensor and automation needs (20 kb/s or below) for wireless communications.

In detection and remote control using such low rate WPAN, the data delay is one of the most important performance criterions. In this paper, we suggest a superframe structure to reduce the delay for transmission between any pair of devices in a beacon-enabled network with star topology.

The rest of this paper is organized as follows: Section 2 summarizes the related works. The proposed scheme is presented in Section 3. Analysis and simulation results are shown in Section 4. Finally, we conclude our paper.

2 Related Works

The superframe structure of IEEE 802.15.4 standard consists of beacon period, active period, and inactive period as shown in Fig. 1. Fig. 1 illustrates two different situations where data is generated at different times and transmitted in WPAN, assuming that a collision does not happen in the network. Low data traffic validates this assumption.

When data is generated in device *A* during an active period, for example, '*a*' of '*F1*' as shown in Fig. 1(a). Device *A* first listens to the network beacon, and synchronizes to superframe structure when the beacon is found. And then, device *A* transmits its data frame, using slotted CSMA-CA, to the coordinator. The PAN coordinator temporarily stores the data before sending it to the device *B*. The device *B* may make contact by transmitting a MAC command to the PAN coordinator requesting the data after receiving a beacon frame from the PAN coordinator. The coordinator acknowledges the successful reception of the data request by transmitting an acknowledgment frame. Now, the PAN coordinator can transmit the data, using unslotted CSMA-CA, to the device *B* during active period of '*F2*' as shown in Fig. 1 (a).

Similarly, when data is generated in device *A* during an inactive period '*b*' of '*F4*' as shown in Fig. 1 (b), data can be also transferred during an active period in the next superframe. So, each device can transmit its data to the coordinator in the next superframe regardless of when data is generated during either active period or inactive period.

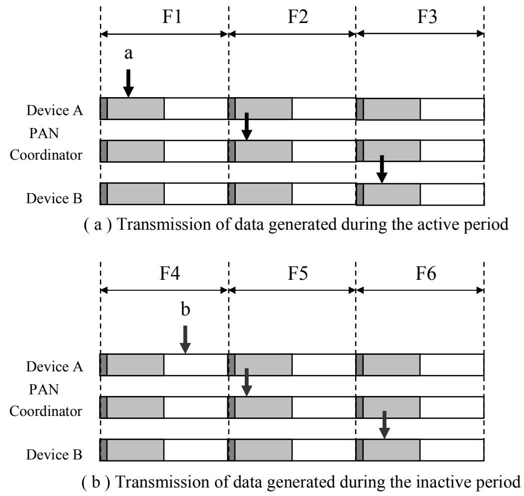


Fig. 1. Data transmission with the IEEE 802.15.4 superframe structure

Assume that each device knows the current superframe structure by receiving a beacon. Then it can transmit data to the coordinator immediately in the current superframe when data is generated during an active period. But, when data is generated during an inactive period, the device has to wait until an active period begins in the next superframe before sending its data to the PAN coordinator. In other words, when data is generated during an inactive period, it cannot be sent to the PAN coordinator in the current superframe although each device knows the current superframe structure. So, this results in a longer average delay between any pair of two devices in WPAN.

3 Proposed Scheme

In this paper, we propose a new scheme to reduce data delay by simply modifying the structure of superframe. We consider a beacon-enabled network with star topology. Data transmission can be classified into two types. One type is involved in transfer of data from a device to a coordinator and the other in transfer of data from a coordinator to a device.

In our scheme, each superframe consists of beacon period, first-half active period, inactive period, second-half active period as shown in Fig. 2. Two half-active periods are located at both ends of a superframe. The total length of beacon period and first-half active period equals to that of *SD*, and second-half active period also has the same duration as *SD*. The vale of *SD* is given by

$$SD = aBaseSuperframeDuration \times 2^{SO-1} \quad (1)$$

BI is set in the same way as the IEEE 802.15.4 standard, which is expressed by

$$BI = aBaseSuperframeDuration \times 2^{BO} \quad (2)$$

In other words, the total length of an active period is equal to that used in the IEEE 802.15.4.

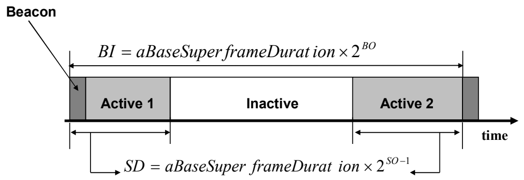
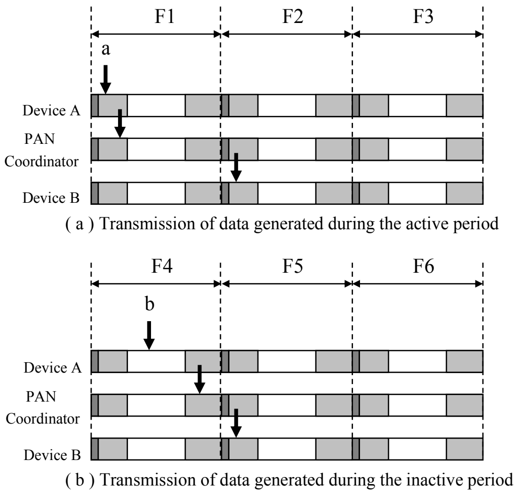


Fig. 2. The proposed superframe structure

It is assumed that data collision does not happen in the network during data transmission in the standard structure. When data is generated during the first-half active period '*a*' of '*F1*' in the device *A* as illustrated in Fig. 3, data is transferred between two devices *A* and *B* in the same fashion as in the standard. So, we get no gain in this case.



(a) Transmission of data generated during the active period

(b) Transmission of data generated during the inactive period

Fig. 3. Data transmission using the proposed superframe structure

However, when data is generated during inactive period '*b*' of '*F3*' in the device *A* as shown in Fig. 3. The device *A* has to wait until it finds active period of the next superframe before sending the data to PAN coordinator. The device *B* waits until it receives a beacon frame from the PAN coordinator since the device *B* cannot request the data to the PAN coordinator. This is because the PAN coordinator need send a beacon frame including destination device's ID before sending data in WPAN with star topology. Finally, the data can be sent to the device *B* during active period of '*F4*', after device *B* receives a beacon frame.

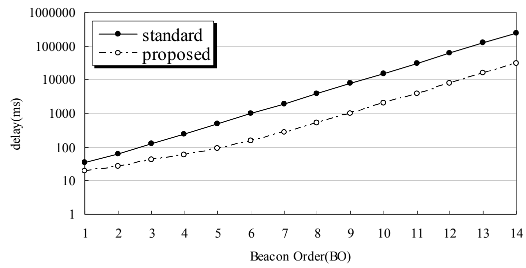
In this case, our scheme can reduce delay for transmission between device *A* and *B* since the PAN coordinator can send a beacon frame to device *B* earlier than the standard after receiving data from device *A*.

4 Performance Analysis

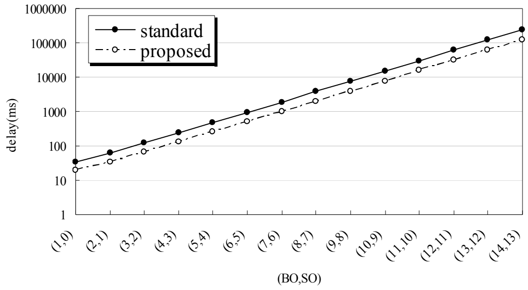
We verify the theoretical mean delay using a computer simulation study. Simulation is carried out using the same beacon-enabled network with star topology as the one used in the theoretical analysis. We assume that a PAN coordinator is deployed in center of network and five devices around a PAN coordinator. Simulation parameters are shown in Table 1.

Table 1. Simulation parameters

Variable	Value
Data transmission rate	250Kbps
Beacon frame length	20byte
Data frame length	30byte
Traffic load	0.01~0.1
Superframe order	0~14
Beacon order	1~14



(a) When, *SO*=0, *BO*=1~14

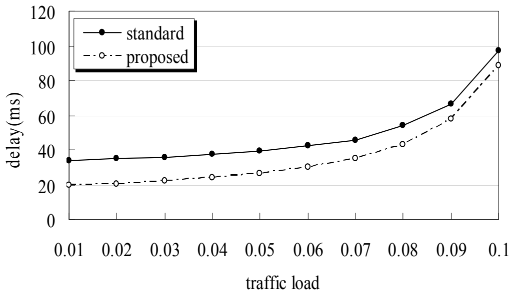


(b) When, *SO*=*BO*-1, *BO*=1~14

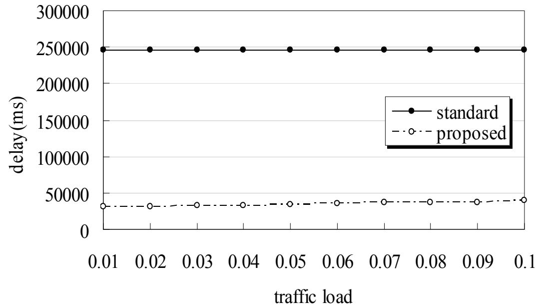
Fig. 4. The experimental mean data delays

Fig. 4 (a) represents the mean delay by computer simulation when *SO* is fixed at 0 and *BO* is changed from 1 to 14 (the same situation as in Fig. 4 (a)). Fig. 4 (b) represent mean delay by computer simulation when *SO* and *BO* is changed from 1 to 14 (the same situation as in Fig. 4 (b)). In the simulation, we assume a very low traffic intensity (specifically, the normalized traffic load is given 0.01) to make a virtually collision-free condition. From these figures, we can observe that data delay increases in proportional to the length of superframe.

Fig. 5 (a) shows the experimental mean data delays as a function of traffic load when traffic load is varied form 0.01 to 0.1. Fig. 5 (a) represents the mean data delay when *SO* is 0 and *BO* is 1. Fig. 5 (b) represents the mean data delay when *SO* is 0 and *BO* is 14, which reflects the situation where the active period is much shorter than the inactive period. From these results, we can observe that our scheme is more efficient than the standard protocol.



(a) When, *SO*=0, *BO*=1



(b) When, *SO*=0, *BO*=14

Fig. 5. The experimental mean data delays as a function of traffic load

5 Conclusion

We propose a new superframe structure to reduce the overall mean transfer delay of data between any pair of devices in a beacon-enabled network with star topology. We can reduce the overall mean data delay by simply modifying the IEEE 802.15.4 superframe structure. Our scheme tries to give a transmission opportunity as soon as possible in the current superframe to data generated during inactive period.

Both theoretical analysis and computer simulation show that our scheme is more efficient than the standard protocol in the aspect of data delay performance. Our scheme shows its beneficial gain more apparently as the length of *BI* increases.

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